

Prediction of Excretion of Manure and Nitrogen by Holstein Dairy Cattle^{1,2}

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ABSTRACT

A compilation of N balance data (n = 1801) was partitioned into four groups to define the mean excretion of manure and N and to develop empirical equations to estimate these excretions from Holstein herds. Mean excretion of manure for cows that averaged 29 kg/d of milk production was 3 kg/d per 1000 kg of body weight (BW) more than the value for dairy cows reported by the American Society of Agricultural Engineers; N excretion was 0.09 kg/d per 1000 kg of BW higher than the value reported by the American Society of Agricultural Engineers. Mean excretion of manure and N for cows that averaged 14 kg/d of milk production and that for nonlactating cows were substantially lower than the values reported by the American Society of Agricultural Engineers. Growing and replacement cattle excreted 10 kg/d per 1000 kg of BW more manure and 0.11 kg/d per 1000 kg of BW more N than was reported by the American Society for Agricultural Engineers for beef cattle. Estimation of manure and N excretion was more accurate than mean values when using regression equations that included variables for milk production, concentration of crude protein and neutral detergent fiber in the diet, BW, days in milk, and days of pregnancy. Equations that contained intake variables did not significantly affect predictions of manure and N excretion, and the use of such equations is discouraged unless dry matter intake is meas-

ured and not estimated. Accurate estimates of excreta output could improve the planning of storage and handling systems for manure and the calculation of nutrient balances on dairy farms.

(**Key words:** nitrogen, cattle, manure, environment)

Abbreviation key: ASAE = American Society of Agricultural Engineers, DOP = days of pregnancy, EMU = Energy Metabolism Unit

INTRODUCTION

Advances in milk production and the expansion of dairy herds have increased the need for improved manure management and whole farm nutrient balance. Adequate manure storage is needed for convenience, nutrient recycling, prevention of pollution, and avoidance of manure spreading when weather or soil conditions are unfavorable. In cold climates, up to 6 mo (or more during severe winters) of storage are often needed. The capacity of manure storage depends on the number of days of storage desired or required, the number of cattle (including estimates of future expansion), the type (solid, liquid, or both) and amount of manure excretion, the type and amount of bedding, and the amount of nonmanure material (e.g., rain, snow, wash water, parlor wastes) that enter the storage unit. In addition, manure storage requirements must be adjusted for the amounts of manure voided but not placed in the planned unit. A critical factor in the design of storage facilities for manure management and the assessment of nutrient balances on dairy farms is the estimate of manure excretion and composition. Current standards for manure production and N excretion were developed for lactating cows and for growing beef cattle by the American Society of Agricultural Engineers (ASAE) (1). Data reported by the ASAE (1) for manure represent urine and feces as voided by the animal and does not include bedding material.

Standards for manure production and characteristics are used to plan new facilities or to expand existing ones. Currently, the range of manure production

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¹Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

²The researchers have produced a spreadsheet containing the equations reported in Tables 4, 5, and 6 to aid in the transfer and application of their research. The spreadsheet can be requested with the manuscript from the researchers.

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by lactating dairy cows is 69 to 103 kg/d per 1000 kg of BW (1). Although intake and digestibility of feed DM and protein have a significant impact on excretion, these variables are not readily available for the prediction of manure and N output. However, using animal and dietary characteristics that can be obtained more readily may improve the accuracy of estimating manure output and may lead to more reliable capacity estimates of facilities that are needed for manure storage.

Environmental problems that may arise from N losses are significant. Producers need more accurate estimates of N excretion by nonlactating cows, growing cattle, and replacement heifers in addition to estimates of the N excreted by lactating cows to evaluate economic and environmental impacts on farm nutrient balance. Standards (1) indicate that dairy cows excrete a total of 0.35 to 0.55 kg of N/d per 1000 kg of BW, but this amount has not been partitioned into fecal and urinary sources. Most producers know the stage of lactation and milk production of their cows and the protein and fiber concentration in the rations fed. When this information is combined with an estimate of BW, the prediction of excretion of manure and N for all classes of cattle on the farm may be more accurate than the use of a standard mean.

Objectives for this research were 1) to define the average manure production and N excretion of Holstein cattle using data from calorimetric studies in the Energy Metabolism Unit (EMU) at Beltsville, Maryland and to compare those data with the standards recommended by the ASAE (1), 2) to develop empirical equations for improving estimates of excretion that use easily obtainable animal and diet characteristics, and 3) to estimate the annual manure production and N excretion of Holstein dairy herds with different levels of milk production.

MATERIALS AND METHODS

Indirect respiration calorimeters have been in operation at the EMU since 1960 to determine the energy balance of dairy and beef cattle. The total EMU data file from energy balance trials conducted over the last 30 yr was restricted to contain only studies with Holstein cattle that were not infused with supplemental nutrients. Fifty-six experiments with 1801 energy balance trials were included in the EMU N data file, which consisted of data from 334 cows (2.0 to 15.4 yr of age) and 75 growing heifers and steers (0.8 to 1.6 yr of age). Lactating cows were assigned to one of two groups based on milk production. The group of cows that produced >20 kg/d of milk during the balance

trial averaged 29 kg/d of milk and represented a herd that produced 9000 kg of milk annually. The group of cows that produced ≤ 20 kg/d of milk during the balance trial averaged 14 kg/d of milk and represented a herd that produced 4000 kg of milk annually. All growing heifers and steers were assigned to a group of growing and replacement cattle. Data were not used when urine was contaminated by overflow from waterers. A regression between urinary volume and DMI was developed to detect outlying data. Outliers ($n = 194$ of 1995 total observations) were deleted when urinary volume (liters) exceeded $30 + 0.5 \times \text{DMI}$ in kilograms.

The total mixed diets contained 0 to 100% forage. Forage or fiber sources in the diets were alfalfa, corn, or orchardgrass silages; alfalfa, brome grass, orchardgrass, or timothy hays; cottonseed hulls; or freshly cut fescue grass. Forage treatments consisted of alfalfa and orchardgrass silages treated with formic acid or formaldehyde and ammoniated corn silage. Dried forages were fed pelleted, wafered, or chopped. Energy ingredients were barley, beet pulp, corn, corn earlage, high moisture corn, dried whey, oats, or wheat bran in cracked, crimped, ground, rolled, or whole forms. Blood meal, brewers dried grains, corn gluten meal, cottonseed meal, distillers dried grains, fish meal, linseed meal, soybean oil meal, sodium caseinate, or urea represented the protein ingredients. Supplemental fat was provided by cottonseed, Megalac® (Church and Dwight Co., Inc., Princeton, NJ), or soybeans.

Composite samples of diets, orts, and feces were dried at 65°C and ground through a 1-mm screen. The DM of diets, orts, and feces was determined by drying at 105°C in a forced-air oven. Fiber analyses were based on the methods of Goering and Van Soest (4), except that sodium sulfite was not used for all NDF analyses. Nitrogen was determined by the macro-Kjeldahl method (2) for fresh (undried) samples of diets, orts, urine, and feces. Cows and heifers were catheterized for urine collection. Urine from steers was collected with a vacuum urinal system (16). Urine collection vessels were preacidified with a preservative (350 g of potassium dichromate, 5 L of distilled water, and 3.75 L of phosphoric acid).

The EMU N data file contained information about the intakes and concentrations of dietary DM, CP, ether extract, ash, gross energy, OM, NDF, ADF, hemicellulose, cellulose, sulfuric acid lignin, neutral detergent solubles corrected for ash ($100 - \text{NDF} - \text{ash}$), and nonfiber carbohydrate ($100 - \text{NDF} - \text{CP} - \text{ether extract} - \text{ash}$). Animal data included age, BW, production of milk and milk protein, DIM, and days of pregnancy (DOP). Nitrogen balance was calculated

(N balance = intake N – fecal N – urinary N – milk N – scurf N). Water intake ($n = 1581$) and milk fat production ($n = 892$) were not included as independent variables because data were not available for all observations in the EMU N data file.

The GLM and REG procedures of SAS (13) were used to evaluate three statistical models. Model 1 used the STEPWISE REG procedure to include variables with regression coefficients that were significant ($P < 0.15$). The GLM procedure was used with Model 2 to evaluate the prediction potential of independent variables that could be accurately determined by or were readily available to producers, their consultants, engineers, or policy makers. Prediction equations were developed for each class of Holstein cattle. Linear coefficients were retained in the regression when a quadratic or interaction coefficient was significant ($P < 0.01$). Model 3 expanded the number of variables used in Model 2 equations to evaluate the potential improvement in prediction. The STEPWISE REG procedure was used to identify variables that explained variation in the residuals of Model 2. These variables were added to Model 2 equations to obtain Model 3 equations, which were evaluated using the GLM procedure.

RESULTS AND DISCUSSION

Lactating cows in the EMU N data file had milk production and milk composition that were representative of a dairy herd that produced 7000 kg of milk annually, and dietary characteristics were similar to those recommended by the NRC (10) (Table 1). Cows that averaged 29 kg/d of milk production had greater DMI than did cows that averaged 14 kg/d of milk production (3.0 and 2.2% of BW, respectively). These intakes are about 90% of current NRC (10) recommendations and may reflect the effects of nominal feed restriction in the chambers to minimize orts. Mean tissue energy and N balance were positive, suggesting that cows generally did not secrete milk at the expense of body reserves. Similarly, water intake was 57% greater for cows that averaged 29 kg/d of milk production than for cows that averaged 14 kg/d of milk production. The amount of water in milk, urine, and feces was about 70 and 85% of the water consumed (drinking plus feed) by replacement cattle and lactating cows, respectively.

In most of the EMU trials, nonlactating cows were fed the same diets as lactating cows but at restricted intakes (about 1% of BW/d). These diets contained a

TABLE 1. Means and standard deviations of cattle and dietary observations in the N data file from the Energy Metabolism Unit (Beltsville, MD).¹

Item	All lactating cows		Cows averaging 29 kg/d of milk ²		Cows averaging 14 kg/d of milk ³		Nonlactating cows		Growing and replacement cattle	
	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD
Cattle, no.	994		590		404		521		286	
Age, yr	5.2	2.2	5.2	1.7	5.9	2.6	6.2	2.3	1.1	0.2
BW, kg	607	73	603	66	614	82	680	73	298	53
DMI, kg/d	16.2	3.8	17.9	3.4	13.7	2.8	6.8	2.1	5.4	1.3
Water, ⁴ L/d	62.1	22.5	72.7	19.3	46.2	17.0	22.2	12.3	10.7	7.6
Milk, kg/d	22.8	9.4	29.0	6.6	13.8	4.6	...	...	...	...
CP, %	3.2	0.4	3.1	0.3	3.4	0.4	...	...	...	...
Fat, ⁵ %	3.6	0.7	3.5	0.7	3.6	0.7	...	...	...	...
Dietary DM, %	66.8	20.1	63.0	19.3	72.2	20.1	70.3	20.5	27.9	10.3
Ash, %	6.3	1.1	6.4	1.0	6.1	1.2	7.0	1.7	7.5	1.6
CP, %	16.1	2.4	16.6	2.2	15.5	2.6	15.9	2.5	18.2	3.7
ADF, %	19.5	4.3	19.8	3.8	19.0	4.9	21.2	7.2	36.1	9.5
NDF, %	33.8	7.3	34.3	6.9	32.9	7.9	35.7	10.0	53.9	14.2
DIM	163	83	120	58	226	73	...	...	...	...
DOP ⁶	33	56	13	32	62	70	62	97	...	...
TEB, ⁷ Mcal/d	0.50	4.9	-0.69	5.2	2.23	3.7	0.83	3.4	2.26	1.8
N Balance, ⁸ g/d	8.9	28.1	4.4	29.9	15.6	23.9	9.8	18.9	22.5	14.8

¹Each observation represents a mean from a balance trial.

²Milk production >20 kg/d.

³Milk production ≤20 kg/d.

⁴ $n = 858$ for all lactating cows, $n = 439$ for nonlactating cows, and $n = 284$ for growing and replacement cattle.

⁵ $n = 892$ for all lactating cows.

⁶Days of pregnancy.

⁷Tissue energy balance.

higher percentage of CP and concentrate than those typically fed to nonlactating cows (Table 1). Water intake for nonlactating cows was about one-third of the mean for lactating cows. Many nonlactating cows used in the EMU studies were not pregnant, resulting in a mean value for DOP that was about 190 d less than that expected for typical dairy cows. Growing cattle included both replacement heifers and growing steers and heifers. Growing and replacement cattle were fed primarily silage diets containing forages that were high in CP (Table 1). The DMI and water intake averaged 1.8 and 3.6% of BW, respectively, for growing and replacement cattle, and were consistent with NRC (10) estimates of DMI.

Rubber mats without additional bedding were used for animal comfort in the EMU calorimeters; therefore, direct comparisons could be made with ASAE (1) standards for the prediction of feces and total manure (wet feces plus urine) that did not include bedding. The mean amount of total manure excreted by cows that averaged 29 kg/d of milk production (Table 2) was similar to the ASAE (1) standard of 86 kg/d per 1000 kg of BW. However, daily excretion of N by these cows was greater than the ASAE (1) standard by 0.092 kg/d. Conversely, the mean amount of total manure and N excreted by cows that averaged 14 kg/d of milk production was less than the ASAE (1) standard. Van Horn et al. (14) estimated manure production by difference (feed input – milk output) for cows in midlactation to be 114.3 kg/d per 1000 kg of BW, which was 28% greater than that observed for cows that averaged 29 kg/d of milk production in the EMU N data file. The excretion of N from cows that averaged 29 kg/d of milk production was 90% of the estimate by Van Horn et al. (14) for cows in midlactation that were fed diets containing 16.4% CP, which was higher than NRC (10) recommendations but comparable with the CP fed to cows in the EMU N data file. The difference in N excretion for cows that averaged 29 kg/d of milk production and estimates by Van Horn et al. (14) could be related to the lower DMI of cows in the EMU N data file. Cows that averaged 29 kg/d of milk production (Table 2) had DMI (17.9 kg/d) and feces excretion (36.2 kg/d) that were similar to those of cows in the studies of Morse (6) (20.9 kg of DMI/d and 38.2 kg of feces/d) and Morse et al. (7) (20.0 kg of DMI/d and 35.8 kg of feces/d). Total manure production in those studies was larger (7 to 12 kg/d) on a per cow basis than the 53.7 kg/d per cow that we observed. This difference in total manure was due to greater urinary excretions, which might have been a result of a warmer environment for the cows in the studies of Morse (6) and Morse et al. (7).

TABLE 2. Means and standard deviations of N intake and excretion of manure and N for classes of Holstein cattle in the N data file from the Energy Metabolism Unit (Beltsville, MD).

Measurement	ASAE ¹ Standard for dairy cattle		Cows averaging 29 kg/d of milk ²		Cows averaging 14 kg/d of milk ³		Nonlactating cows		Growing and replacement cattle		ASAE Standard beef cattle	
	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD
Total manure	86	17	89.0	22.5	65.9	17.3	34.8	11.1	67.5	18.5	58	17
Feces	60		60.0	18.1	41.2	13.8	15.1	7.4	32.6	10.0	40	
Intake N			0.787	0.182	0.549	0.140	0.254	0.086	0.530	0.181		
Total excreta N	0.45	0.096	0.542	0.146	0.399	0.116	0.237	0.077	0.447	0.153		
Fecal N			0.270	0.077	0.192	0.049	0.077	0.029	0.193	0.062	0.34	0.073
Urinary N			0.272	0.093	0.208	0.090	0.160	0.056	0.254	0.110		
Milk N			0.234	0.053	0.121	0.040						

¹American Society of Agricultural Engineers (1).

²Milk production >20 kg/d.

³Milk production ≤20 kg/d.

Nonlactating cows excreted a mean 34.8 kg/d of total manure (Table 2), which was 40% of the ASAE (1) standard for lactating dairy cows and 60% of the ASAE standard for beef cattle. Van Horn et al. (14) estimated the manure production of nonlactating cows to be 64% greater than the mean observed in this study. This discrepancy was most likely the result of restricted intakes of the nonlactating cows and the composition of diets fed in the EMU studies. Similarly, the mean amount of N excreted by nonlactating cows was 53% of the ASAE (1) standard for lactating cows and 70% of the ASAE standard for beef cattle. The mean amount of N excreted by nonlactating cows was 91 and 76% of the estimates reported by Van Horn et al. (14) when their diets contained 11 and 12% CP, respectively.

Total manure output (67.5 kg/d per 1000 kg of BW) by growing cattle in the EMU N data file was 16% greater than the ASAE (1) standard for beef cattle (58 kg/d per 1000 kg of BW). Furthermore, total N excretion was 31% greater for growing cattle in the EMU N data file than the ASAE (1) standard for beef cattle (Table 2), probably because of the high CP percentage of diets fed in the EMU studies. It would be helpful if the ASAE (1) standards included information about manure excretion for all classes of livestock that are normally maintained on dairy farms. This information would be beneficial for estimating manure storage needs in the plan for new production facilities or to expand existing ones. Data from the current study suggested that a single set of values for manure excretion by lactating cows could not be used to estimate accurately the manure storage requirements for an entire dairy farm.

Differences observed between the EMU N data file and the ASAE (1) standards for excretion of manure and N were similar to those observed between farm trials (3) and N balance trials (5). Bulley and Holbek (3) measured N balance on dairy farms and developed relationships to predict N excreted in manure or secreted in milk. Other researchers (3, 12) suggested that the difference between N input from feed and N secretion in milk was a more accurate estimate of N in manure. Although farm and balance trials provide similar estimates of manure production, they provide different estimates of N excretion. Measurements of N balance in EMU trials provided more accurate estimates of excretion of manure and N than those obtained from farm trials (5) because experimental procedures were used to minimize losses of manure and N during collection. Muck and Richards (9) reported that about half of the N excreted by lactating cows was lost from manure before

it reached a storage facility. The majority of N loss in manure has been linked to the loss of ammonia when urease in the feces is mixed with urine. Therefore, accounting for differences in the handling and storage of manure is important to determine the N recycled to the land when spread as manure.

Total N excretion was 69% of the N that was consumed and 2.32 times the N secreted in milk by cows that averaged 29 kg/d of milk production in the EMU N data file, which agreed with the findings of Bulley and Holbek (3) of 71% and 2.45 times, respectively. The calculated total excretion of N, using the difference between N consumed and N in milk, was closer to the observed total excretion of N for cows that averaged 29 kg/d of milk production than for cows that averaged 14 kg/d of milk production in the EMU N data file. The discrepancy between measured and calculated N excretion was related to differences in N balance for tissue deposition, which was greater for cows that averaged 14 kg/d of milk production (15.6 g of N/d) than for cows that averaged 29 kg/d of milk production (4.4 g of N/d).

The large standard deviations for manure and N excretion (Table 2) and the variation in diets and cattle within groups (Table 1) suggest that regression equations may predict excretion more accurately than means. Although they may overlap, regression models can be classified as descriptive or predictive. Descriptive regression models attempt to use a maximum amount of data recorded in a specific experiment to describe the variation in dependent variables and to identify those independent variables that are statistically significant sources of variation. Predictive regression models attempt to use independent variables that are easily available and accurately measured as inputs to obtain robust estimates of dependent variables in a larger data domain than a single data file. Descriptive models are, by definition, data specific; robust predictive models are intended for general use. Criteria other than statistical significance of recorded research observations should be used to select appropriate variables. For example, DMI measured during experiments is often highly correlated with animal response. However, DMI is typically not known or is poorly predicted in field conditions.

Model 1 is a descriptive model designed to determine the upper limits of accuracy to estimate excretion of manure and N using all animal and dietary characteristics that were measured during calorimetry. Model 1 was selected from the complete set of linear, quadratic, and interaction independent variables in the EMU N data file. The R^2 and standard

errors of regression for each dependent variable and class of cattle are given in Table 3. Results indicate that dietary input and animal response variables can explain most of the variation in manure and N excretion by dairy cows and replacement cattle. With the exception of total manure production by nonlactating cows and replacement cattle (for which the range in data was small), the R^2 of the descriptive Model 1 exceeded 0.86. Coefficients of variation suggest that random or unexplained variation in excretion by dairy cattle in the EMU N data file was approximately 10%.

Model 1 yielded equations that provided the best description of variation that was possible for the EMU N data file; however, they might not be the best prediction equations because they require inputs that are unknown or are unavailable to the user. Because DMI is often unknown or is poorly predicted, a subset of variables (Model 2) was selected to develop predictive equations for producers, consultants, engineers, and policy makers. Production and composition of milk can be obtained from sales receipts, DHI records,

or regional and national agricultural statistics. Animal BW, DIM, and DOP are easily obtained or estimated. In addition, CP and NDF in the diet are functions of the feeding and forage program and can be estimated with reasonable accuracy for a specific farm or region when planning manure storage or calculating nutrient balances.

Model 2 equations for prediction were developed using linear or quadratic and interaction variables. The linear prediction equations included milk production, dietary CP and NDF, BW, and DIM to estimate daily excretion of manure and N by lactating cows (Table 4). Excretion of manure and N by nonlactating cows was related to linear functions of DOP, dietary CP and NDF, and BW (Table 4). Body weight and dietary concentrations of CP and NDF were associated with daily excretion of manure and N by growing and replacement Holstein cattle (Table 4). Although the improvement in R^2 and standard errors was small, the inclusion of some quadratic and interaction terms of the variables resulted in a significant statistical improvement. The intercepts of the quadratic equations were not significantly different from 0 (Table 5), and a no intercept model was used to derive regression coefficients in Table 5. Compared with the descriptive models (Table 3), the R^2 were about 50% lower, and the standard errors were 2.5 times greater for prediction equations in Table 5. The utility of Model 1 equations was limited because 1) many of the variables included in the models were selected only because they described the EMU N data file specifically, 2) most variables selected would not be available to potential users of these equations, and 3) some variables were selected without an apparent biological rationale. Perhaps a more valid criterion for evaluating prediction equations is to compare standard errors. In general, equations in Table 5 resulted in standard errors that were 40% of those for group means (Table 2), which indicates that they significantly improve accuracy in the estimation of excretion of manure and N by dairy cattle.

Model 2 equations were designed to predict manure and N excretion using variables that were routinely available or that could be accurately estimated. To determine the potential improvement in the description of variation that could be achieved by additional recorded variables, the residual variation (observed – predicted) for equations in Table 5 was regressed on all linear, quadratic, or interaction terms using the STEPWISE REG procedure of SAS (13). In general, the addition of one to four variables maximized the prediction of residual variation. Variables selected by stepwise regression were related to intake and the

TABLE 3. Number of variables, R^2 , standard errors, and coefficients of variation of models using stepwise regression with linear, quadratic, and interaction terms recorded in the N data file from the Energy Metabolism Unit (Beltsville, MD).

Item	All lactating cows	Non-lactating cows	Growing and replacement cattle
Cattle, no.	994	521	286
Number of variables available	1225	990	946
Total manure			
Number of variables selected ¹	24	13	15
Model R^2	0.864	0.641	0.641
Model SE	5.24	4.58	3.39
Model CV	10.9	19.3	16.8
Feces			
Number of variables selected	41	36	25
Model R^2	0.922	0.936	0.916
Model SE	3.24	1.33	0.90
Model CV	10.2	13.0	9.3
Total excreted N			
Number of variables selected	42	35	28
Model R^2	0.956	0.960	0.970
Model SE	0.020	0.011	0.008
Model CV	6.6	6.8	6.2
Fecal N			
Number of variables selected	70	31	44
Model R^2	0.924	0.935	0.961
Model SE	0.013	0.005	0.004
Model CV	9.2	10.0	6.9

¹ $P \leq 0.15$.

TABLE 4. Regression coefficients and statistics for linear prediction equations by class of animal and type of excretion.

Item	All lactating cows				Nonlactating cows				Growing and replacement cattle			
	Total manure	Feces	Total excreted N	Fecal N	Total manure	Feces	Total excreted N	Fecal N	Total manure	Feces	Total excreted N	Fecal N
Intercept	-21.94	-7.60	-0.440	-0.0916	3.13	-7.00	-0.152	-0.0353	-5.918	-5.226	-0.159	-0.0397
BW, kg	0.0286	0.0256	0.000232	0.0000925	0.00711	0.0121	0.000107	0.0000578	0.0499	0.0258	0.000471	0.000136
DOP ¹	...	...	...	...	0.0214	0.0151	0.0000751	0.0000593	...	...	...	...
DIM	0.0378	0.0238	0.000342	0.000124	...	...	...	...	...	...	...	...
Milk, ² kg/d	1.0689	0.918	0.00649	0.00395	...	...	...	...	...	...	...	...
CP, % of DM	0.0967	-1.077	0.0183	0.00140	0.324	-0.0806	0.0111	0.00125	0.442	0.227	0.00867	0.00276
NDF, % of DM	0.614	0.483	0.00280	0.00138	0.259	0.262	0.00170	0.000691	0.0586	0.0577	-0.000109	0.000120
R ²	0.489	0.590	0.646	0.553	0.157	0.370	0.304	0.234	0.305	0.315	0.782	0.426
SE	10.04	7.28	0.054	0.031	6.96	4.04	0.044	0.018	4.62	2.47	0.021	0.014

¹Days of pregnancy.²Milk contained 3.6% fat and 3.2% protein.

TABLE 5. Regression coefficients and statistics for quadratic prediction equations with 0 intercept by class of animal and type of excretion.

Item	All lactating cows				Nonlactating cows				Growing and replacement cattle			
	Total manure	Feces	Total excreted N	Fecal N	Total manure	Feces	Total excreted N	Fecal N	Total manure	Feces	Total excreted N	Fecal N
CP, % of DM	-2.640	-2.454	-0.0110	-0.00415	2.851	1.098	0.0185	0.00709	-2.594	-0.600	-0.00532	0.00306
(CP) ²	...	...	...	...	-0.0841	-0.0384	-0.000257	-0.000195	0.0919	0.00255	0.0000529	-0.000154
NDF, % of DM	1.421	1.209	0.00412	0.00215	-0.216	-0.204	-0.00371	-0.00152	0.870	0.525	0.00401	0.000789
(NDF) ²	-0.0117	-0.0120	-0.0000503	-0.0000310	...	...	...	...	-0.00832	-0.00497	-0.0000437	-0.00000775
BW, kg	-0.0497	-0.0151	-0.000582	-0.0000666	-0.0170	-0.0120	-0.000194	-0.0000599	0.0892	-0.00854	-0.000185	-0.000178
DOP ¹	...	...	...	...	0.0235	0.0163	0.0000859	0.0000653	...	...	...	...
DIM	0.149	0.0928	0.00108	0.000357	...	...	...	...	...	...	...	...
(DIM) ²	-0.000306	-0.000195	-0.00000207	-0.000000683	...	...	...	...	...	...	...	...
Milk, ² kg/d	0.962	0.633	0.00270	0.00147	...	...	...	...	...	...	...	...
Milk × NDF	0.00224	0.00710	0.000104	0.0000671	...	...	...	...	...	...	...	...
BW × CP	0.00502	0.00260	0.0000506	0.00000970	...	...	...	...	...	...	...	...
BW × NDF	...	...	...	...	0.000736	0.000706	0.00000795	0.00000332	-0.00222	0.00174	0.0000345	0.0000166
R ²	0.541	0.633	0.701	0.589	0.176	0.393	0.308	0.262	0.389	0.390	0.822	0.477
SE	9.53	6.89	0.050	0.030	6.88	3.96	0.044	0.017	4.34	2.34	0.019	0.013

¹Days of pregnancy.²Milk contained 3.6% fat and 3.2% protein.

interactions of intake and chemical composition. The intake variables identified by the STEPWISE REG procedure were then systematically evaluated using Type III sums of squares in the GLM procedure (13) to determine those that improved the statistics of the quadratic and interaction equations in Table 5 most significantly.

The addition of DMI and the interaction of DMI and CP significantly improved the description of excretion in the EMU N data file (Table 6). The inclusion of intake variables increased the R^2 to within 90% of the maximum that was observed for Model 1 (Table 3). The greater R^2 of equations in Table 6 compared with those in Table 5 suggested that they might be better for prediction. However, higher R^2 simply indicate a better description of variation in the EMU N data file, not necessarily better prediction. If estimated intake is used as an input variable, the error associated with this estimate must be combined with the error of the excretion equations in Table 6, which may result in a total error for predicting excretion that is larger than that of the equations given in Table 5. In addition, milk production, dietary NDF or energy density, and DMI are correlated. An estimated DMI that does not correspond with animal or dietary characteristics could result in larger errors in the prediction of the excretion of manure and N. Therefore, caution should be exercised when using the equations in Table 6 to predict manure and N excretions when the independent variable DMI must be estimated. We recommend that equations in Table 5 be used when DMI is not measured.

To evaluate the effects of milk production and diet composition on excretion of manure and N (Table 7), predictions were made using the equations in Tables 4, 5, and 6 with the following inputs: BW was held constant at 600 kg; DIM was held constant at 150 d; and daily milk production, dietary CP percentage, and dietary NDF percentage were set to match NRC (10) recommendations. Compared with the linear model, the more complex quadratic model resulted in little change in estimates of the excretion of manure and N for the lowest two levels of milk production but predicted lower excretion estimates for cows that produced 40 kg of FCM daily (Table 7). Although the R^2 were significantly higher when DMI variables were added to the quadratic equations (Table 6), the prediction of manure and N excretion, assuming NRC (10) conditions, was not different from that predicted by equations that did not include intake as independent variables (Table 7).

The use of regression equations to estimate the amount of manure and N excreted by dairy cows

TABLE 6. Regression coefficients and statistics for expanded prediction equations that include intake and intake interaction variables.

Item	All lactating cows				Nonlactating cows				Growing and replacement cattle			
	Total manure	Feces	Total excreted N	Fecal N	Total manure	Feces	Total excreted N	Fecal N	Total manure	Feces	Total excreted N	Fecal N
(kg/d)												
CP, % of DM	-1.103	-1.283	-0.000922	0.00130	1.497	0.0862	0.00249	0.00215	-2.351	-0.549	-0.00442	0.00336
(CP) ²	...	...	...	...	-0.0372	0.00280	-0.0000700	-0.0000405	0.0825	0.00738	0.0000766	-0.000118
NDF, % of DM	0.745	0.687	-0.000101	-0.000151	-0.124	-0.179	0.0000366	-0.00106	0.791	0.298	0.00190	-0.000779
(NDF) ²	-0.00282	-0.00504	0.00000234	-0.0000299	...	...	...	...	-0.00747	-0.00233	-0.0000193	0.0000105
BW, kg	-0.0743	-0.0571	-0.0000379	0.000154	-0.0179	-0.0155	-0.0000337	-0.0000553	0.174	0.0101	0.000136	-0.0000681
DOP ¹	...	...	...	...	0.00586	0.00206	-0.0000581	0.0000397	...	...	...	...
DIM	-0.0165	-0.0378	0.000118	-0.000175	...	...	...	...	...	...	...	...
(DIM) ²	0.0000379	0.0000789	-0.000000173	0.000000379	...	...	...	...	...	...	...	...
Milk, ² kg/d	0.0391	-0.0864	-0.00289	-0.00160	...	...	...	...	...	...	...	...
Milk × NDF	-0.00724	-0.000407	0.0000501	0.0000373	...	...	...	...	...	...	...	...
BW × CP	0.00406	0.00320	0.00000393	-0.0000113	...	...	...	...	...	...	...	...
BW × NDF	...	...	...	...	0.000384	0.000495	0.000000690	0.00000189	-0.00784	-0.000979	0.000000488	-0.00000114
DMI, kg	4.047	4.030	-0.00211	0.00181	2.603	2.476	-0.00120	0.00804	-4.995	-0.00195	-0.00943	0.00116
DMI × CP	-0.0373	-0.0798	0.00131	0.000549	-0.0132	-0.0366	0.00145	0.0000249	0.327	0.107	0.00154	0.000672
R ²	0.796	0.876	0.924	0.844	0.516	0.867	0.922	0.873	0.446	0.701	0.944	0.858
SE	6.37	4.01	0.025	0.018	5.29	1.86	0.015	0.007	4.15	1.65	0.011	0.007

¹Days of pregnancy.

²Milk contained 3.6% fat and 3.2% protein.

would provide producers with more accurate projections than existing ASAE (1) standards. The ASAE (1) standards for excretion of manure, when adjusted to kilograms per cow per day, fall between the predictions for cows that produce 20 and 30 kg of FCM daily (Table 7). The estimate for total excretion of N by the ASAE (1) standard was similar to the prediction for cows that produce 20 kg of FCM daily (Table 7).

TABLE 7. Estimates of daily excretion of manure and N from 600-kg Holstein cows at 150 DIM that correspond to NRC (10) production and diet characteristics.

Item	Milk production		
	20 kg of FCM/d ¹	30 kg of FCM/d ²	40 kg of FCM/d ³
	(kg/d)		
Linear model ⁴			
Total manure	46.0	55.5	65.2
Feces	31.2	38.4	45.7
Total excreted N	0.257	0.336	0.416
Fecal N	0.135	0.174	0.213
Quadratic and interaction model ⁵			
Total manure	48.1	57.3	66.2
Feces	32.8	39.3	45.1
Total excreted N	0.271	0.344	0.410
Fecal N	0.140	0.175	0.205
Quadratic and intake model ⁶			
Total manure	49.0	58.9	65.9
Feces	33.5	40.6	44.7
Total excreted N	0.274	0.348	0.410
Fecal N	0.142	0.178	0.205

¹Diet and production characteristics: 1.52 Mcal of NE_L/d according to the NRC (10), 15% dietary CP according to the NRC (10) (used as an input variable), 34% dietary NDF (estimated to correspond with the NE_L requirement for dairy cows and used as an input variable), 21.3 kg of 3.6% milk fat/d [milk production corresponding with the FCM production predicted by the NRC (10); used as an input variable], and 16.5 kg/d of DMI [estimated from Table 6-1 of the NRC (10)].

²Diet and production characteristics: 1.62 Mcal of NE_L/d according to the NRC (10), 16% dietary CP according to the NRC (10) (used as an input variable), 31% dietary NDF (estimated to correspond with the NE_L requirement for dairy cows and used as an input variable), 31.9 kg of 3.6% milk fat/d [milk production corresponding with the FCM production predicted by the NRC (10); used as an input variable], and 20.1 kg/d of DMI [estimated from Table 6-1 of the NRC (10)].

³Diet and production characteristics: 1.72 Mcal of NE_L/d according to the NRC (10), 17% dietary CP according to the NRC (10) (used as an input variable), 28% dietary NDF (estimated to correspond with the NE_L requirement for dairy cows and used as an input variable), 42.6 kg of 3.6% milk fat/d [milk production corresponding with the FCM production predicted by the NRC (10); used as an input variable], and 22.8 kg/d of DMI [estimated from Table 6-1 of the NRC (10)].

⁴See Table 4.

⁵See Table 5.

⁶See Table 6.

Amounts of manure and manure N increased as production increased in agreement with the linear increases that were observed (5) as DMI, CP intake, and milk production increased. Van Vuuren et al. (15) observed increased fecal N when ryegrass was partially replaced by starch or fiber and suggested that this increase might be a result of increased microbial matter from either ruminal or hindgut fermentations. Furthermore, the observed increase in fecal N was coupled with a decrease in urinary N (15).

Many of the nonlactating cows in the EMU N data file were not pregnant, which might have biased estimates of excretion for typical cows during the dry period. Similarly, many diets fed during the EMU studies did not represent typical diets for nonlactating cows. The equations in Table 5 can be used to estimate excretion by nonlactating cows kept under more typical conditions. Excretion was calculated (Table 8) with BW held constant at the mean of the data file (680 kg), and concentrations of dietary CP and NDF were set to the mean of the data file (16% CP and 36% NDF) and to more typical values for nonlactating cows fed diets recommended by NRC (10) to contain 12% CP and 1.25 Mcal of NE_L/kg of DM. To meet these recommendations, the NDF concentration of forage diets was estimated to be 60%. The value for DOP was set to represent lactating (150 d) and nonlactating cows during the dry period (250 d). The DMI were estimated by dividing daily NE_L requirements (megacalories) by 1.25 Mcal of NE_L/kg of DM.

Although DOP was statistically significant to the regression equations, the change in DOP from 150 to 250 d resulted in less than an 8% change in excretion predictions. Using the linear and quadratic models, dietary composition had a more dramatic effect, and the typical diet for nonlactating cows resulted in larger excretions of total manure and smaller losses of total N than the mean observed in the EMU N data file; however, the predictions were considerably less than ASAE (1) standards. The inclusion of intake variables in the models resulted in substantial differences in manure and N excretions for nonlactating cows, which might have been caused by the development of an intake related regression coefficient using EMU N data in which the cattle were fed restricted amounts. Predictions indicate that a typical diet for nonlactating cows with lower CP than observed in the EMU N data file would result in slightly decreased total N excretion, and a greater proportion of this N would be from feces. Fecal N was about 30% of intake N for nonlactating cows in the EMU N data file, and

predictions indicate that fecal N would increase to more than 35% of intake N under typical feeding conditions. Nonlactating cows typically represent 15% of the cow herd, and, because they excrete less manure and N than lactating cows, this information is important in the determination of nutrient balances and manure storage requirements for the whole farm.

Because mean concentrations of dietary CP in the EMU N data file were higher than those recommended by the NRC (10), variables in Table 9 were set to correspond to the mean of the data file and to NRC (10) recommendations, which represent more typical feeding programs for growing and replacement dairy cattle. Quadratic models resulted in higher and more accurate estimates of manure and fecal excretion for all growing and replacement cattle. However, N excretion was higher for light cattle and was lower for heavy cattle when quadratic models were compared with the linear models using NRC (10) recommendations.

Per 1000 kg of BW, manure and N excretion by nonlactating cows and growing Holstein cattle was less than that estimated by the current study for

lactating cows. Further, the ASAE (1) standards for dairy cattle would overestimate, and the ASAE (1) standards for beef cattle would underestimate, the current manure and N excretion for nonlactating cows and growing Holstein cattle. The lack of information for comparison with excretion of manure and N for growing and replacement cattle, and nonlactating cows in the EMU N data file indicates a need for additional research.

The milk production levels (20, 30, and 40 kg of FCM/d) selected by the NRC (10) were used to establish a range in annual herd production that illustrated the effects of increased production on expected excretion of manure and N (Table 10) for the whole farm. Equations developed from the EMU N data file (Table 5) indicated that the excretion of manure from lactating cows that produced >6100 kg of FCM annually would be larger than the ASAE (1) standards. Thus, for high producing dairy herds, the use of ASAE (1) standards could underestimate storage needs for manure by 25% or more. Estimates of manure production for lactating cows that produced 9150 kg of FCM annually were 84% of the estimates of Van Horn et al.

TABLE 8. Estimates of dairy excretion of manure and N from 680-kg nonlactating Holstein cows with changes in days of pregnancy and diet characteristics that match NRC (10) recommendations.

Item	Stage of pregnancy			
	150 d		250 d	
	EMU ¹ Data file ²	NRC ³	EMU Data file	NRC
	(kg/d)			
Linear model ⁴				
Total manure	25.7	30.6	27.8	32.7
Feces	11.6	18.3	13.1	19.8
Total excreted N	0.171	0.167	0.178	0.174
Fecal N	0.058	0.069	0.064	0.075
Quadratic and interaction model ⁵				
Total manure	26.3	30.9	28.6	33.2
Feces	11.9	18.3	13.6	20.0
Total excreted N	0.172	0.169	0.180	0.178
Fecal N	0.059	0.070	0.066	0.077
Quadratic and intake model ⁶				
Total manure	24.4	36.7	25.0	37.3
Feces	10.4	23.3	10.6	23.5
Total excreted N	0.158	0.198	0.152	0.192
Fecal N	0.053	0.089	0.053	0.090

¹Energy Metabolism Unit (Beltsville, MD).

²Diet characteristics: 16% dietary CP and 36% dietary NDF; 6.8 kg/d of DMI.

³Diet characteristics: 12% dietary CP according to the NRC (10) (used as an input variable) and 60% dietary NDF [estimated to correspond with the NE_L requirement for dairy cows at 1.25 Mcal/kg of DM according to the NRC (10); used as an input variable]; 11.1 kg/d of DMI [estimated by dividing the daily NE_L requirement (megacalories) by 1.25 Mcal of NE_L/kg of DM].

⁴See Table 4.

⁵See Table 5.

⁶See Table 6.

(14), but excretion of N was similar to their findings when milk production and dietary CP were similar. The discrepancies between ASAE (1) standards and our estimates or the estimates of Van Horn et al. (14) for manure and N excretion could have a serious impact on the planning of manure storage and handling systems.

Equations in Table 5 provide a basis for estimating total excretion of manure and N without bedding; however, the amount and composition of manure in storage is different. The composition of stored manure can be influenced by handling and storage conditions, which influence rate of decomposition and degree of dilution (8, 9, 11). Muck and Richards (9) reported that less N was lost from manure when the mean daily air temperature in the barn was <5°C. Losses increased as temperature increased, and these losses

can represent 60% of the total N excreted (9). Manure storage facilities that load from the top lost a greater amount of their total N (29 to 39%) than did manure storage facilities that load from the bottom (3 to 8%) (8). Manure slurry from pits beneath slotted floors in dairy barns lost between 4.4 and 8.4% of the initial N over 285 d of storage in concrete tanks (11). Therefore, animal excretion and manure decomposition during storage should be considered when a nutrient management program is being designed that utilizes dairy cattle manure.

CONCLUSIONS

A data file was established and used to predict the excretion of manure and N (without bedding material). Excretion of manure and feces was estimated

TABLE 9. Estimates of daily excretion of manure and N from growing and replacement Holstein cattle with different BW and diet characteristics that match NRC (10) recommendations.

Item	EMU ¹ Data file ² 300 kg of BW	NRC		
		200 kg of BW ³	300 kg of BW ⁴	400 kg of BW ⁵
		(kg/d)		
Linear model ⁶				
Total manure	20.2	13.6	17.9	22.3
Feces	9.7	6.0	8.4	10.8
Total excreted N	0.133	0.070	0.099	0.128
Fecal N	0.057	0.037	0.045	0.054
Quadratic and interaction model ⁷				
Total manure	20.6	14.5	21.6	29.9
Feces	10.7	8.2	10.5	12.0
Total excreted N	0.141	0.093	0.117	0.126
Fecal N	0.061	0.046	0.049	0.043
Quadratic and intake model ⁸				
Total manure	20.2	14.5	20.6	29.2
Feces	10.0	8.3	11.2	14.4
Total excreted N	0.134	0.093	0.121	0.142
Fecal N	0.056	0.047	0.054	0.060

¹Energy Metabolism Unit (Beltsville, MD).

²Diet characteristics: 18% dietary CP and 54% dietary NDF; 5.4 kg/d of DMI.

³Diet characteristics: 16% dietary CP according to the NRC (10) (used as an input variable) and 42% dietary NDF [estimated to correspond with the NE_L requirement for dairy cows at 1.25 Mcal/kg of DM according to the NRC (10); used as an input variable]; 4.6 kg/d of DMI [estimated by dividing the daily NE_L requirement (megacalories) by 1.25 Mcal of NE_L/kg of DM].

⁴Diet characteristics: 14% dietary CP according to the NRC (10) (used as an input variable) and 46% dietary NDF [estimated to correspond with the NE_L requirement for dairy cows at 1.25 Mcal/kg of DM according to the NRC (10); used as an input variable]; 6.5 kg/d of DMI [estimated by dividing the daily NE_L requirement (megacalories) by 1.25 Mcal of NE_L/kg of DM].

⁵Diet characteristics: 12% dietary CP according to the NRC (10) (used as an input variable) and 51% dietary NDF [estimated to correspond with the NE_L requirement for dairy cows at 1.25 Mcal/kg of DM according to the NRC (10); used as an input variable]; 8.9 kg/d of DMI [estimated by dividing the daily NE_L requirement (megacalories) by 1.25 Mcal of NE_L/kg of DM].

⁶See Table 4.

⁷See Table 5.

⁸See Table 6.

TABLE 10. Projected annual excretion of manure and N from a herd of Holstein cows as influenced by milk production (does not include bedding or storage losses).¹

Lactating herd²				
Milk production, kg per cow	6100	9150	12,200	ASAE ³
Total manure, tonne	1493	1778	2055	1601
Feces, tonne	1021	1220	1401	1117
Total excreted N, tonne	8.4	10.7	12.7	8.4
Fecal N, tonne	4.4	5.4	6.4	
Complete herd including nonlactating cows and replacement heifers⁴				
Milk production, kg per cow	6100	9150	12,200	
Total manure, tonne	2334	2618	2895	
Feces, tonne	1433	1632	1812	
Total excreted N, tonne	12.7	15.0	17.0	
Fecal N, tonne	6.1	7.0	8.1	

¹Excretion calculated using quadratic equations for lactating, nonlactating, and growing and replacement cattle (Table 5) assuming NRC (10) dietary recommendations.

²n = 85 lactating cows; 600 kg of BW.

³American Society of Agricultural Engineers; calculations were based on dairy standards (1).

⁴n = 85 lactating cows, 600 kg of BW; 15 nonlactating cows, 680 kg of BW; 30 2-yr-old heifers, 400 kg of BW; 25 yearling heifers, 300 kg of BW; and 25 heifer calves, 200 kg of BW.

from regression equations for lactating cows, nonlactating cows, and growing and replacement dairy cattle that included BW, dietary CP and NDF, milk production, DIM, and DOP. Data for all classes of Holstein cattle were fitted to linear and quadratic models. Although the R^2 for predictive equations were greater when intake terms were included, the improvement in estimates of manure and N excretions was not significant. It is recommended that equations containing intake terms for predicting manure and N excretion not be used when the intakes must be estimated. Estimates of excretion of manure and N on the whole farm indicated that current standards need to be updated to reflect higher milk production and to include the complete dairy herd, including lactating cows, nonlactating cows, growing cattle, and replacement cattle.

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